US ERA ARCHIVE DOCUMENT

Evaluation of Sanitary Sewer Systems as a Source of Pathogen Contamination to Municipal Water Supply Wells



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Program



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Madison and Fitchburg Water Utilities

Madison Metropolitan Sewer District

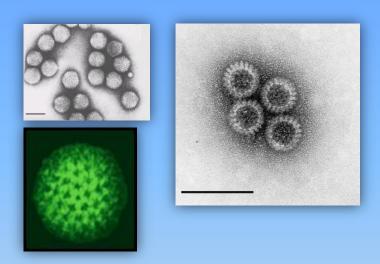
Bureau of Drinking Water and Groundwater, WDNR

Virus Transport through a bedrock aquitard

We have detected human enteric viruses in water produced from deep (300 m) municipal wells finished in bedrock below an aquitard.

These viruses originate at the land surface; the most likely source is municipal sewage.

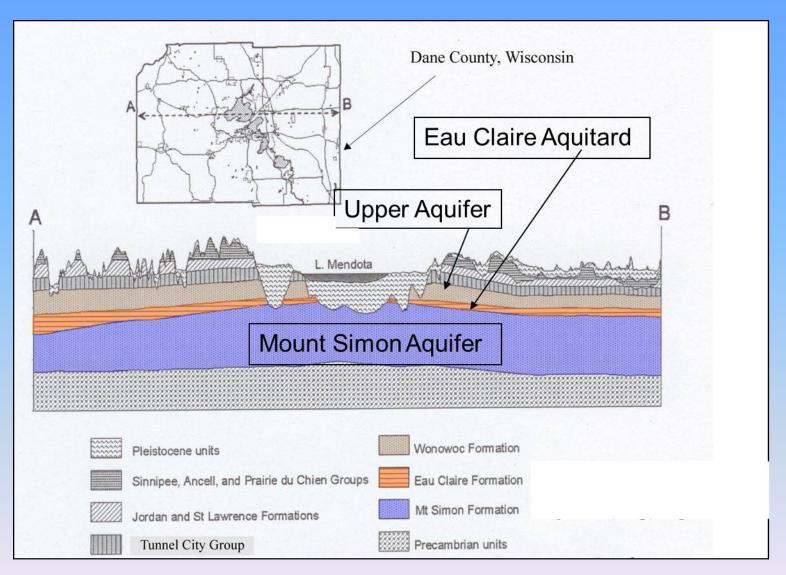
The virus lifetime is thought to be <2 years; thus presence in deep aquifers suggests much more rapid transport than previously expected.



Viruses (e.g., adenovirus, enterovirus, rotavirus)

1,438 pathogens infect humans of which 32 are waterborne in the U.S.

See Borchardt and others, 2007, Environmental Science and Technology. 41(18); 6606-6612



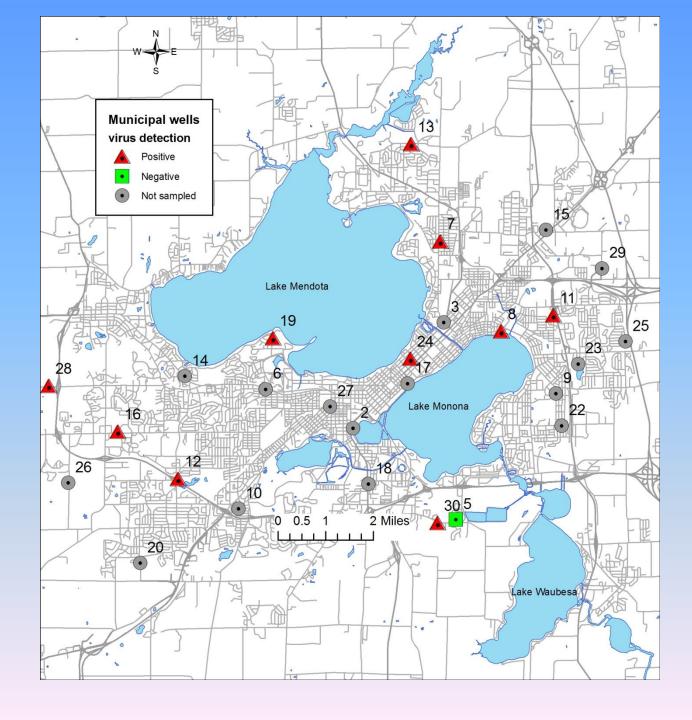
Background...A surprise for hydrogeologists...

- Initial virus sampling conducted in Madison as part of AWWARF-funded study of aquitards
- We wanted to find out whether viruses were present in a deep, confined bedrock aquifer
- We did not expect to find any because the travel times were supposedly much longer (10s-100s of years) than the virus lifetimes (~2 years)

Wells sampled 2007-2009

Human enteric viruses have been detected periodically in every well sampled.

These wells produce water from beneath a regional aquitard.



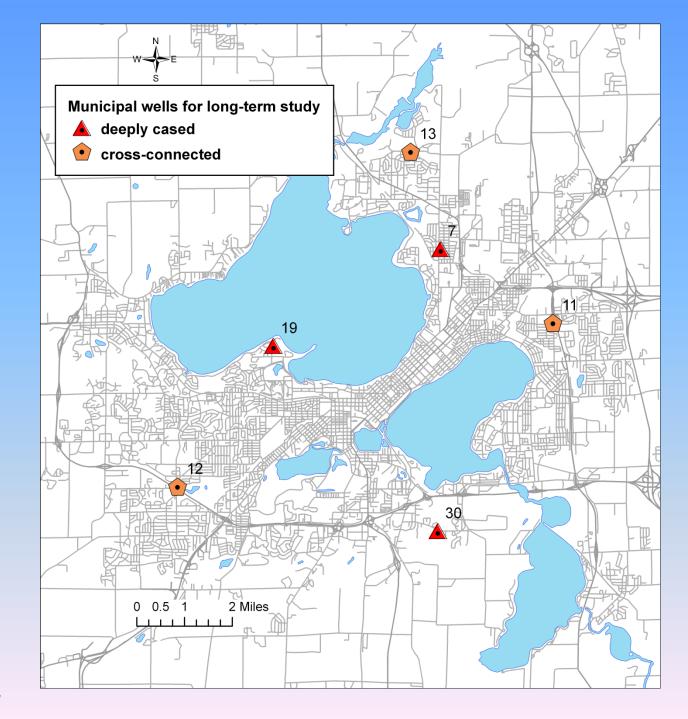
A surprise for hydrogeologists...

- We found viruses in <u>every well sampled</u>, though not in every sample.
- These findings raised questions, such as:
 - Where do the viruses come from?
 - How do they reach the wells?
 - How can they move so rapidly?
- Coincidence between virus types present in sewage and virus types present in deep groundwater

Wells sampled 2007-2009

We began with 10 wells in a variety of locations to be sure we had virus-positive wells to work with.

We later reduced the sampling to 6 wells due to budget and logistic considerations.





Virus Sampling

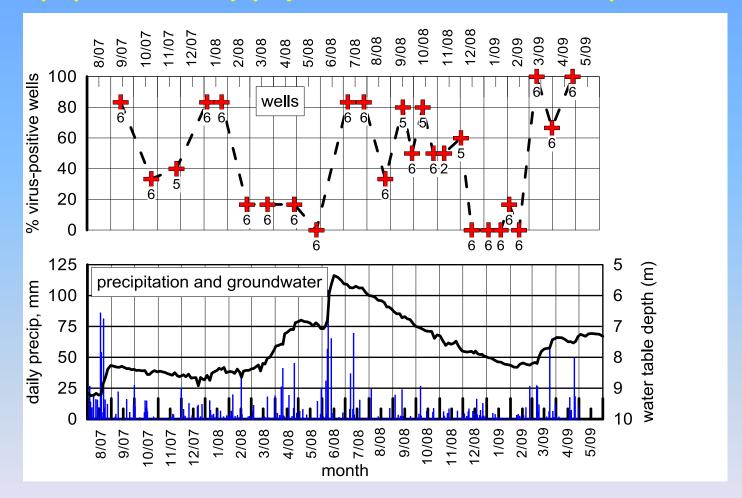








47% (70 of 148) samples collected from six deep public supply wells were virus positive



Groundwater recharge events correlate to virus detections, suggesting rapid transport Bradbury et al., in press, ES&T

Sanitary sewers leak outward



Sewage exfiltration rates: 0.3 to 300 gallons/hr/mile Chisala and Lerner, 2008.

Are there impacts on urban groundwater...are there significant problems associated with aging underground pipes and our drinking water quality?



16 different species (serotypes) of viruses were identified in wells, sewage, and lake water during this study, and in many cases wells and sewage contained identical virus serotypes. Detected viruses include Enteroviruses echovirus 3, echovirus 11, Coxsackie A16, B3, and B4, Adenoviruses 2, 7, 31, and 41.

Sampl	le round	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
median sample date		14-Sep-07	24-Oct-07	26-Nov-07	19-Dec-07	24-Jan-08	26-Feb-08	24-Mar-08	28-Apr-08	27-May-08	7-Jul-08	28-Jul-08	25-Aug-08	17-Sep-08	29-Sep-08	13-Oct-08	27-Oct-08	10-Nov-08	2-Dec-08	16-Dec-08	7-Jan-09	23-Jan-09	3-Feb-09	16-Feb-09	11-Mar-09	31-Mar-09	27-Apr-09
	A41	Х		Х	Х		Х			Х	Х	NS	Х	Х			Х	Х	Х	Х	Х	Х	Х	Х	Х	Х	Х
	A31				Х				Х	Х	Х	NS	Х		Х	Х	Х	Х	Х	Х	Х	Х	Х		Х		Х
	A2	Х	Х		Х	Х		Х				NS														X	
4)	E3		Х								Х	NS							Х	Х	Х						
sewage	E30											NS												Х	Х		
e &	A7										Х	NS															
0,	E11		Х	Х			Х		Х			NS															
	CoxA16											NS															
	CoxB3											NS															
	CoxB4			Χ								NS												Х			
	A41	Х		Х	Х	Х		Х			Х	Х	Х	Х	Х	Х	Х	Х	Х				Х		Х	Х	Х
	A31					Х					Х	Х	Х				Х		Х						Х		
	A2	Х		Х	Х	Х					Х			Х													Х
S	E3		Х								Х	Х															
Vell	E30																								Χ	Х	
all wells	A7	Х				Х					Х	Х															
	E11		Х	Х					Х																		
	CoxA16																										
	CoxB3											Х				Х											
	CoxB4																								Х		
	A41	Х	NS	NS	NS	NS	NS	NS		NS	Х	NS		Х	Х	Х	Х	Х	Х			Х			Х		
	A31		NS	NS	NS	NS	NS	NS		NS		NS				Х		Х									
	A2	Х	NS	NS	NS	NS	NS	NS	Х	NS	Х	NS															
	E3		NS	NS	NS	NS	NS	NS		NS	Х	NS														Х	Х
lakes	E30		NS	NS	NS	NS	NS	NS		NS	Х	NS															
<u>a</u>	A7		NS	NS	NS	NS	NS	NS		NS		NS															
	E11		NS	NS	NS	NS	NS	NS		NS		NS												Х	Х		
	CoxA16		NS	NS	NS	NS	NS	NS		NS		NS															
	CoxB3		NS	NS	NS	NS	NS	NS		NS		NS															
	CoxB4		NS	NS	NS	NS	NS	NS		NS		NS															

There is coincidence between serotypes present in sewage and serotypes present in groundwater.

Samp	ole round	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
median	sample date	14-Sep-07	24-Oct-07	26-Nov-07	19-Dec-07	24-Jan-08	26-Feb-08	24-Mar-08	28-Apr-08	27-May-08	7-Jul-08	28-Jul-08	25-Aug-08	17-Sep-08	29-Sep-08	13-Oct-08	27-Oct-08	10-Nov-08	2-Dec-08	16-Dec-08	7-Jan-09	23-Jan-09	3-Feb-09	16-Feb-09	11-Mar-09	31-Mar-09	27-Apr-09
sewage	A41 A31 A2 E3 E30 A7 E11 CoxA16 CoxB3 CoxB4	x	X	X	X	×	x	x	x	X	X X	NS NS NS NS NS NS NS	X	X	x	Х	X	X	X	XXXX	X	X	X	X	X	x	X
all wells	A41 A31 A2 E3 E30 A7 E11 CoxA16 CoxB3 CoxB4	x x	X	x	x	X X X	>	X	x		X X X	X X	x	X	X	X	X	X	X				X		X	x	x x
lakes	A41 A31 A2 E3 E30 A7 E11 CoxA16 CoxB3 CoxB4	X	NS	NS	NS	NS	NS	NS	X	NS	X X X	NS		X	X	X	X	X	X			X		x	x	х	x



Implications

- We see human viruses moving across a regional aquitard much more rapidly than predicted by traditional porousmedia models or environmental isotopes
- Serotype correlations suggest that the transport is rapid (weeks to months)
- The virus source is apparently leaking sewers
- Fractures, breeches, and/or cross-connecting wells are apparently degrading aquitard integrity

Municipal wells in urban settings appear to be more vulnerable to pathogenic contamination than generally assumed by utility managers, the public or many hydrogeologists. Discrete features in our traditional porous-media aquifers, along with well construction issues, profoundly impact well vulnerability.

Project goals

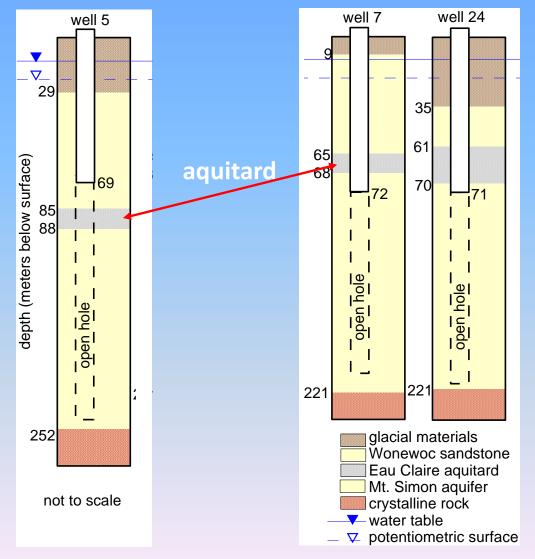
- Quantify the temporal and spatial distribution of viruses in <u>shallow</u> groundwater
- Is there a relationship between viruses detections and conditions of near-by sewers?
- What is the nature of preferential pathways in the apparent rapid transport of viruses

Supply well construction

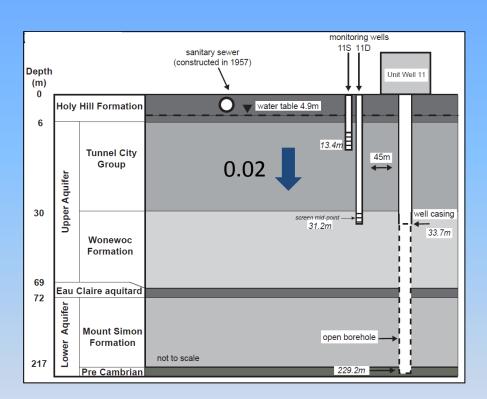
Pumping induces large (>> 1) vertical gradients across the aquitard

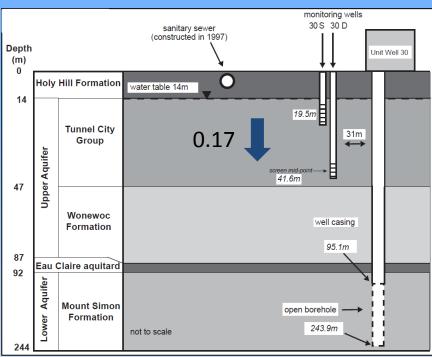


multi-aquifer well confined aquifer well



Typical site design

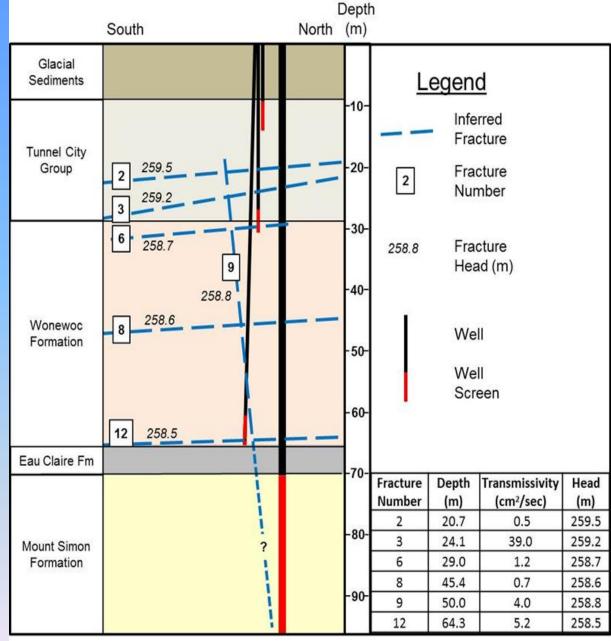




We have seven such sites; each site sampled every two weeks

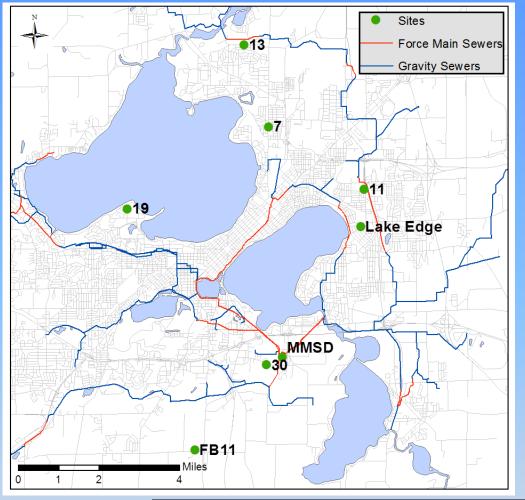


Straddle packer used to isolate, sample, and test discrete intervals of a test well.

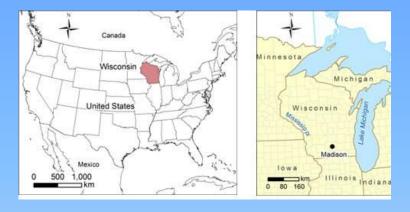




Gellasch and others, Hydrogeology Journal, 2012.



Study design

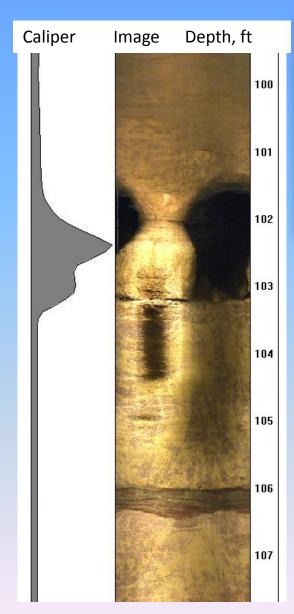


Site	Aquifer	Year of construction	Well depth (feet)	Casing depth (feet)	Sewer Age	Sewer Material	Tritium (TUs)	Chloride (mg/L)	Nitrate (mg/L)
Well 11	multi-aquifer	1959	752	111	1957	clay	5.5	44.2	2.5
Well 13	multi-aquifer	1959	780	128	1958	clay	1.6	7.8	1.7
Well 7	confined	1939	736	238	1939	clay	5.1	11.6	<0.1
Well 19	confined	1970	710	260	1960	clay	3.7	4.4	<0.1
Well 30	confined	2003	800	312	1997	plastic	0.4	36	<0.1
FB Well 11	confined	2007	1000	402	2000	plastic	0.04	2.4	<0.1
Lake Edge	NA	NA	NA	NA	1952	clay	6	9.2	1.5

Site characterization and development

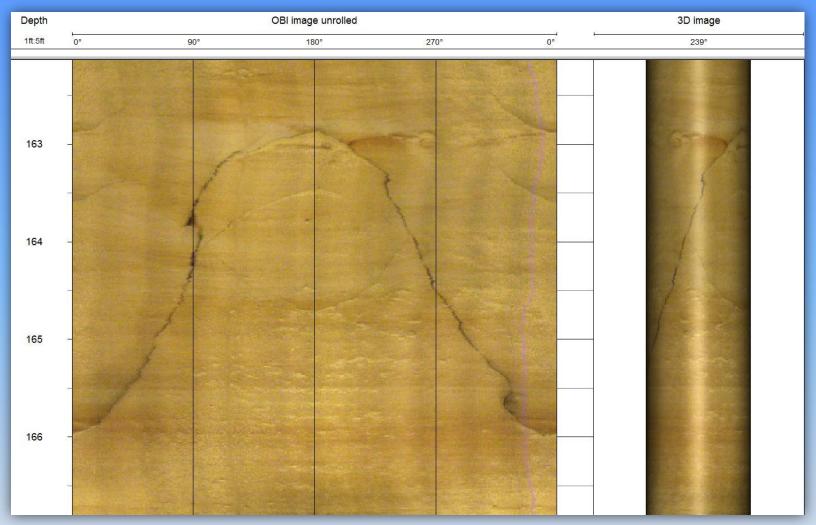








Drilling
Geophysical logging
Borehole imaging
Flowmeter testing
Hydraulic testing
Monitoring well completion



Optical Borehole Imaging (OBI) logs provide Excellent information on fractures and voids.

Logs are oriented.

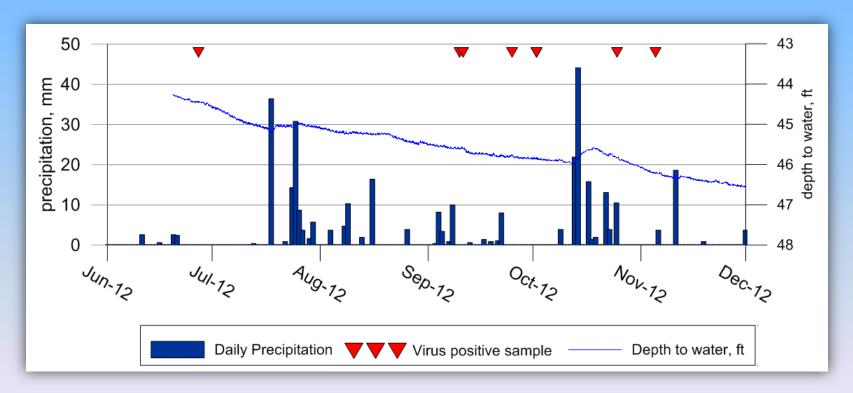
High-angle fracture in sandstone



Preliminary virus detections

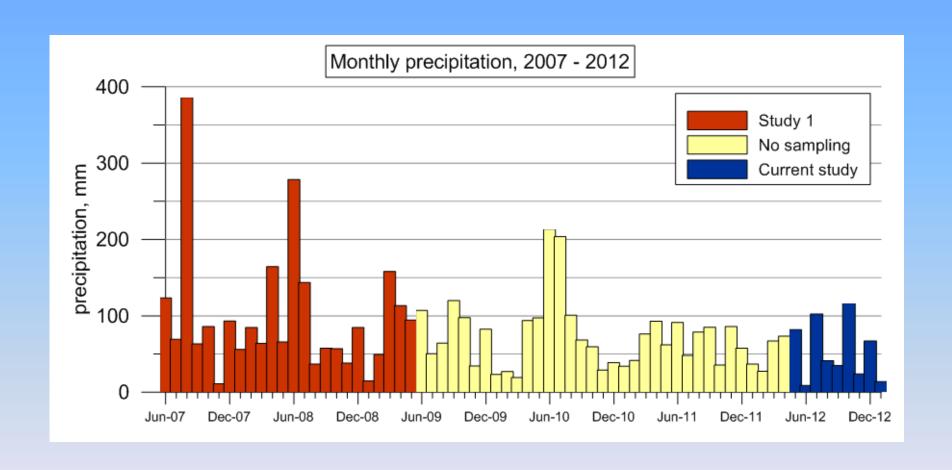
55%, 251 out of 456, of samples collected and analyzed

3.2% of the samples are virus positive (47% positive in first study)





Does precipitation drive sewer exfiltration?



Some observations

- Fractures and multi-aquifer wells in combination provide fast and high-volume preferential pathways in the urban environment
- 2. Lower virus detection rate than in previous work supports role of precipitation in sewer exfiltration
- 3. We need a rainy spring

Selected Publications

- Borchardt, M.A., K.R. Bradbury, M.B. Gotkowitz, J.A. Cherry, and B.L. Parker. 2007. Human enteric viruses in groundwater from a confined bedrock aquifer. *Environmental Science & Technology* 41 no. 18: 6606-6612.
- Borchardt, M.A., S.K. Spencer, B.J.A. Kieke, E. Lambertini, and F.J. Loge. 2012. Viruses in Non-Disinfected Drinking Water from Municipal Wells and Community Incidence of Acute Gastrointestinal Illness. *Environmental Health Perspectives* 120 no. 9: 1272–1279.
- Bradbury, K.R., M.A. Borchardt, M. Gotkowitz, S.K. Spencer, J. Zhu, and R J. Hunt. 2013. Source and transport of human enteric viruses in deep municipal water supply wells. *Environmental Science & Technology*. Available online; DOI: 10.1021/es400509b
- Gellasch, C. A.; Bradbury, K. R.; Hart, D. J.; Bahr, J. M., Characterization of fracture connectivity in a siliciclastic bedrock aquifer near a public supply well (Wisconsin, USA). *Hydrogeol J* 2012, 1-17
- Gellasch, C. A.; Wang, H.F., Bradbury, K. R.; Bahr, J. M., and Lande, L.L. 2013. Reverse water-level fluctuations associated with fracture connectivity. *Groundwater*. Published online: DOI: 10.1111/gwat.12040

